ROOF BOLTING IN THE UNITED STATES

BY EDWARD THOMAS

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HISTORY

The origin of roof bolting as a means of roof support is obscure. During the past 23 years a method was developed by the St. Joseph Lead Co. at its mines in southeastern Missouri, ranging from occasional use of single bolts with small bearing plates to systematic networks of bolts utilizing continuous bearing plates. Officials of this company are not certain which of its employees suggested their use. Many instances of occasional use of roof bolts have come to light during the past few years in widely separated mining districts, such as in West Virginia, Alabama, Illinois, Colorado, and Wyoming bituminous coal mines, and in Pennsylvania anthracite, Lake Superior iron, and Colorado lead-zinc mines. A few of the known installations have been in place as long as 40 years.

These installations usually were made to supplement wooden timbering in mine openings where space was constricted, although it had been reported that roof bolting was started as a systematic means of roof support in at least three instances but was abandoned because the cost of installation was excessive. The extra expense above that of conventional timbering could not be recaptured through economies resulting from increased efficiency, such as would be gained through mechanized mining.

Roof bolting was first mentioned in mining literature in an article by W. W. Weigel[3] in Engineering and Mining Journal of May 1943, in which he described the use of bolts with 4-inch channel bearing plates in mines of the St. Joseph Lead Co.

In a series of six articles appearing between September 1945 and October 1946 in Colliery Engineering, Z. S. Beijl,[4] a mining engineer of Delft, Holland, suggested a method of roof bolting suitable for longwall mining based on experiments in Great Britain during World War II. Beijl justified this new method with a theory of rock pressures; he concluded that they consisted of three kinds of compressive forces - (1) pressure from the vertical weight of the overlying strata, (2) hydraulic pressure set up in the rock itself as a result of the exothermic process developed during the transition from peat to coal, and (3) orogenetic pressure.

In the spring of 1947, at the No. 7 mine of the Consolidated Coal Co.[5] in Illinois, an experiment was started in which roof bolts were used as an adjunct to conventional timbering in mechanized mining. At this mine, an immediate roof of thinly bedded shale is anchored to a main roof of heavily bedded limestone. The bolts are supplemented with wooden posts, particularly in rooms and sometimes with crossbars.

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[3] Weigel, W. W., Channel Irons for Roof Control: Eng. and Min. Jour., vol. 144, No. 5, May 1943, pp. 70-72.

[4] Beijl, Z. S., Rock Pressure and Roof Support: Colliery Eng. 6 parts, September 1945 to October 1946.

[5] Conway, C. C., Roof Support with Suspension Rods: Min. Cong. Jour., June 1948, pp. 32-37.

The Concord mine of the Tennessee Coal, Iron & Railroad Co. was the first coal mine in which roof bolts were utilized exclusively as a means of roof support. The coal bed at this mine is overlain by thinly bedded weak shales, ranging in thickness from 18 to 38 inches, that are bolted to an overlying sandstone stratum by means of vertical bolts 52 inches long. These bolts, installed on 4-foot centers, are now used instead of wooden crossbars, which had to be replaced with steel crossbar sets in main haulageways and air courses. The experimental project at the Concord mine was initiated in May 1948 and for several months was confined to one section of the mine; however, inasmuch as the method of roof support was so successful, roof bolting was adopted exclusively throughout the mine, and since May 1949 the use of wooden roof supports has been discontinued.

Concurrently with the Concord mine experiment, the Tennessee Coal, Iron & Railroad Co. tried roof bolting in its Alabama iron-ore mines, and several were converted to this method of support. The ore-mine installations demonstrated effectively the feasibility of consolidating beds of thinly stratified rock to form competent roof. These differed from the coal-mine installation in that no massive stratum was available in which to anchor bolts.

The Bureau of Mines first became interested in roof bolting early in 1947, because it appeared to be a solution to the problem of "cutters" or unpredictable caving in several coal-mining regions in the United States.6/ 7/8/9/ Studies of these phenomena in northern West Virginia and central Pennsylvania indicated that planes of weakness in roof material - shale and sandstone - developed because of "weathering" and subsequent breaking down of the cementing materials. When a stratum of roof separates from an adjacent one, it becomes an individual beam across the mine opening. It was deduced, therefore, that if the span of the opening was reduced to several smaller spans by introducing rigid support, the beam deflection at each small span after the bedding planes opened would be within the elastic limit of the rock, and failure would be prevented. Enough timber support, however, could not be placed between the mine floor and the roof without obstructing the working space and thus precluding application of mechanized mining methods. It was further deduced that if the natural cementing material, which had

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6/ Thomas, Edward, Seeling, C. H., Perz, F. Hensen, M. V., Control of Roof and Prevention of Accidents from Falls of Rock and Coal: Bureau of Mines Inf. Circ. 7471, 1948, pp. 8-9.

7/ Thomas, Edward, Suspension Roof Support: Coal Age, July, 1948, pp. 86-88.

8/ Thomas, Edward, Conventional Timbering vs. Suspension Supports: Bureau of Mines Bull. 489 (Proceedings of the 5th International Mine Safety Conference 1948), 1950, pp. 175-181. Also, Mechanization, February 1949, pp. 147-152.

9/ Thomas, Edward, Barry, A. J., and Metcalfe, Arthur, Suspension Roof Support: Bureau of Mines Inf. Circ. 7533, 1949, 13 pp.

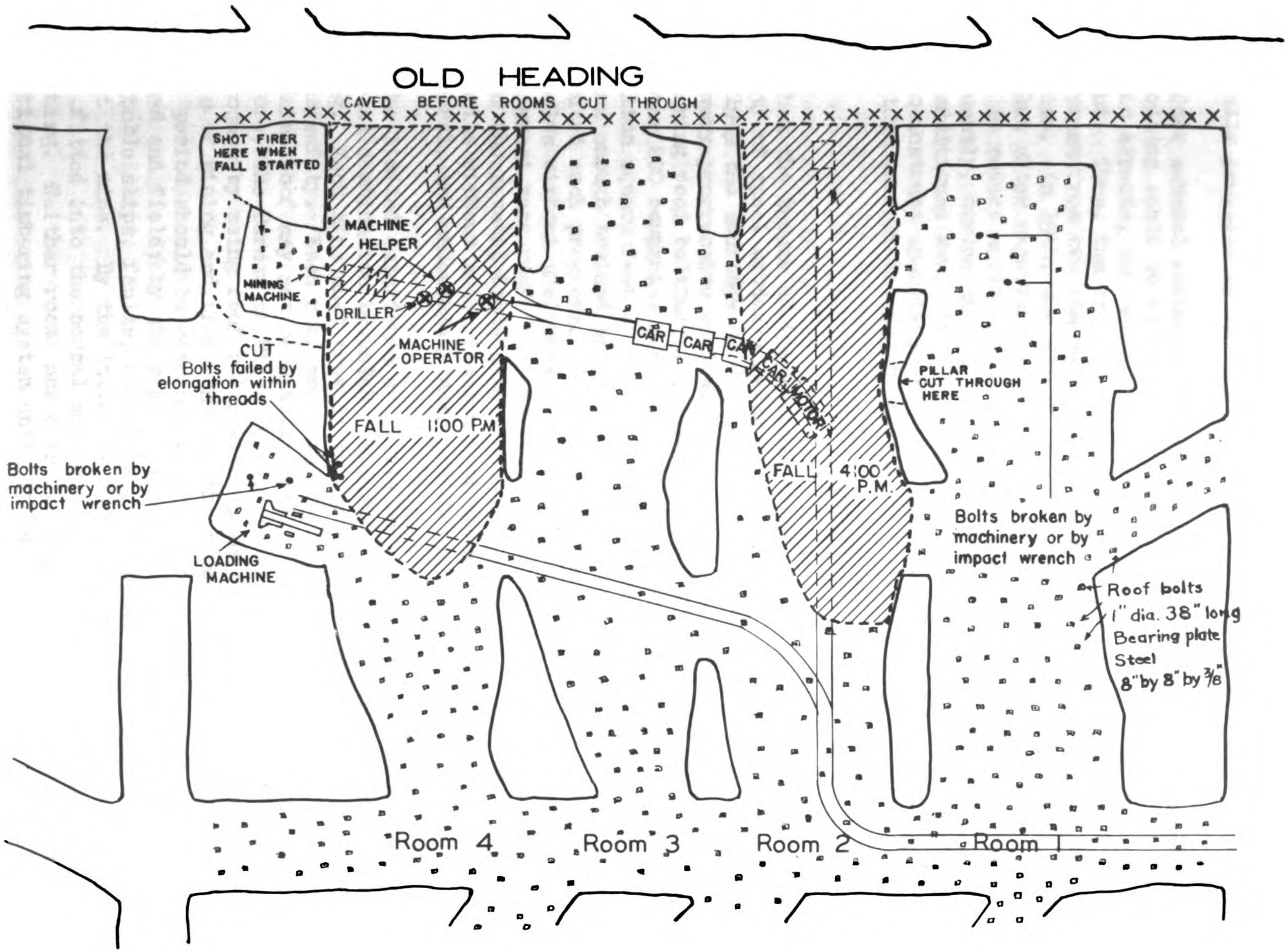

Figure 1. - Detail of roof-fall accident (scale 1" = 30').

consolidated these thin strata, could be replaced by uniting them mechanically at frequent intervals, the ultimate effect would be the same as that originally provided by the cementing material.

After several successful experimental projects, it became obvious that roof bolting could be applied to coal mining; and, in addition to the economic aspects, the safety of workmen was improved beyond that at first apparent. Thus, the coal-mining industry became interested in this new development from two standpoints - prevention of accidents and efficient operation. In 1945, the Bureau of Mines assigned two engineers to roof-control work, but after experiments with roof bolting indicated that the method was likely to reduce accidents from falls of roof this activity was expanded. Consequently, during the latter part of 1948 and the first months of 1949 seven additional men, later increased in 1949 to ten were assigned as "service men" to instruct operating personnel and State and Federal coal-mine inspectors in roof-bolting technique.

SAFETY

When the Bureau of Mines became interested in roof bolting, there was a scarcity of steel products owing to World War II and its aftermath. In April 1949 the shortage eased, and steel became generally available. Virtually every progressive coal-mining company in the United States then began considering roof bolting as a means of roof support, and by the end of the year over 200 companies were utilizing the method to support approximately 14 million square feet of roof surface. At first the Bureau of Mines did not have enough trained personnel for consultation before the companies instituted such programs. Some operators were foolhardy enough to install roof bolts without preliminary experimentation; consequently, it was feared that a great many roof-fall accidents would occur. Appeals therefore were made to the several State mine-inspection agencies to restrict the use of roof bolts without authorization from them. This appeal was well-received in general, and undoubtedly many serious accidents were avoided.

The limited experience available had indicated that there was no universal combination by which one could standardize the method of roof bolting. Each mine must provide an experimental installation to insure maximum safety. Each roof presents its own problems, and the experience with other mine roof may not be exactly applicable to a particular new installation. Therefore, the Bureau of Mines recommends experimental installation with each new project by using roof bolts with conventional timbering and conventional methods of mining and then removing the timbers. The duration of an experimental period should be governed by previous experience in the particular coal bed and field; by the regularity of bedding, such as freedom from unpredictable slips, faults, horsebacks, etc.; and by the caliber of organization at the mine. By the latter is meant the ease with which the roof bolting can be fitted into the normal mining cycle without gaps in the continuity of bolting. Neither rooms nor entries should be driven wider than with the conventional timbering system until it is proved beyond doubt that the roof of the conventional width of opening can be supported safely with roof bolts;

then, if wider openings are contemplated, a new experimental installation should be undertaken. Moreover, if any significant changes occur in the characteristics of the roof, a new experimental period with conventional timbering should be undertaken.

To date, one accident (fig. 1), in which three men were killed, can be attributed directly to roof bolting; the accident would not have occurred if a method of roof support with conventional timbering had been in use. The company is a substantial concern that heretofore had an excellent safety record. A roof-bolting experiment to suspend 14 inches of "draw slate" from a good, hard main roof was started last November in entries 25 feet wide. Approximately 2,200 linear feet of entry roof was bolted successfully during the succeeding 2 months, using vertical bolts 1 inch in diameter and 38 inches long on approximately 4-foot centers longitudinally and transversely. During the latter part of December, without further preliminary preparation or advice, the equipment was applied to rooms intended to be driven 40 feet wide on 55-foot centers, leaving 15-foot pillars between them. Actually, the pillars left were less than 5 feet thick in several places, and at one point a pillar was cut through. Although the dimensions of the bolts were not changed, the center-to-center distance, both longitudinally and transversely, was increased from 4 to approximately 7 feet.

On January 31, after four such rooms had been driven into a remnant of a pillar and lifts had been taken from the pillar between No. 4 room and old abandoned workings, the roof in No. 4 room fell, killing 3 men. The total span at the time actually was 200 feet, even though the roof was supported somewhat by the inadequate pillars between rooms 1 and 4. Nevertheless, the roof beam did not fail until one abutment of the span was being "gouged out."

Three other accidents involving fatalities in mines using roof bolts were due to causes familiar to all who have worked in coal mines, namely, "the man did not set a safety post before he worked under unsupported roof near the face," or "the supports were not installed according to the system laid out." Such factors can be controlled only through proper supervision and discipline regardless of the method of roof support in use.

TECHNIQUES OF INSTALLING ROOF BOLTS

In applying roof bolting to coal mines, it was logical that first installations should follow the St. Joseph Lead Co.'s practice, which had been successful for more than 20 years. Moreover, since the method had been in common use for over 20 years, neither the method nor the basic design of the bolts could be patented; therefore, the Bureau did not spend public funds to promote products that could be produced by one manufacturer only. The first Bureau-sponsored installations utilized the slit-rod-and-wedge bolts, which are not foolproof and probably will be replaced by improved types of bolts in the future. Several anchoring devices have become available recently, but whereas they correct some of the undesirable features of the slit-rod-and-wedge bolt, frequently other more or less objectionalbe features are introduced. Nevertheless, today approximately 80 percent of the bolts being installed continue to be the slit-rod-and-wedge type.

Drilling

It is estimated that 60 percent of the roof rocks overlying coal beds can be drilled by rotary drills equipped with the newer carbide alloy bits. Rotary drills have not been used successfully where as little as a 1-inch stratum of consolidated sandstone or even occasional occlusions of pyrites must be penetrated.

It should be remembered that before roof bolting was introduced, compressed air was used in bituminous-coal mines only occasionally, such as for drilling "up holes" that were necessary to blast for ventilation overcasts and for drilling roof rock in haulage entries in some low-coal mines. Such drilling usually was done with small, hand-hold, hammer-type drills supplied with compressed air from portable compressors, frequently of low capacities, that were designed for intermittent service.

Methods of Tightening and Anchoring Bolts

Although the slit-rod-and-wedge type of anchor bolts does not afford an entirely satisfactory installation, it is used widely, and its use is likely to continue for some time. It has the following disadvantages:

1. Very close tolerances must be observed as to depth of hole, requiring close supervision. If the hole is too long, the bolt will not seat properly and is therefore worthless for roof support. If the hole is too short, too much of the bolt will protrude from it.

2. Sometimes considerable experimentation is required to determine the correct size of wedge with respect to the diameter of hole.

3. Bolt diameters less than 1 inch are not recommended, because the amount of metal removed in making a slot (1/8 inch wide) is constant, and with bolts less than 1 inch in diameter the base of the slot is a point of weakness.

4. At best it provides a very small actual bearing surface, and in rocks in which plastic flow is a factor the bolt will not maintain its tension.

5. The most efficient and effective method so far discovered of anchoring this type of bolt is to apply a percussion-type drill to the end of the rod after first protecting the threads with a dolly. Inasmuch as all effective tools for this purpose are pneumatic, use of this type of bolt is obviated when electric rotary drills are used. In fact, the main selling point for most competitive roof bolts is that a compressed-air tool is not required for their installation. The Bureau of Mines does not recommend the recovery of roof bolts in room-and-pillar mining because of the hazards of doing so.

Advantages of the slit-rod-and-wedge type of bolt, if installed properly, are:

1. It cuts a dovetail while being driven home, and in tension the bolt will fail before it can be pulled out of a hole. In a series of hydraulic-jack pull tests made by a larger user of these bolts, the average failure in tension was at 13.5 tons. These tests were made on bolts that were selected at random and had been installed at least 6 months.

2. It is not patentable and may be purchased on a free market.

Virtually everyone agrees that the primary effect of roof bolting is to consolidate several strata into a thick beam, holding the several parts rigidly together as a single unit and preventing flexure at points where the elastic limit might be exceeded. This may be done by one of two methods: (1) By anchoring bolts at the upper and lower limits and, through tension on the bolt, preventing side thrust of the strata, or (2) by having a pin, possibly of wood, in contact with the stratum throughout its length, thus eliminating the necessity for an anchoring device or a bearing plate, as suggested by one inventor. In the first method, it is obvious that as much as possible of the tensile strength of the steel should be utilized when the bolt is installed. Preliminary tests of 1-inch bolt installations on 4-foot centers (16-foot roadways) indicate that, when the bolts are loaded to 50 percent of their rated yield-point strength after installation, no additional subsequent loading need be expected. This allows a factor of safety if a bolt corrodes, and if future tests prove this conclusively the method probably will be recommended as standard practice.

For efficiency in installation as well as uniformity of loading the bolts, it is at present recommended that the nuts be tightened with a power impact wrench, even though commercially available wrenches of this type are not entirely satisfactory. No available electric impact wrench is capable of tightening a 1-inch nut to approximately 250 ft. lbs. of torque.

Pneumatic impact wrenches, which are available, were not designed with roof bolting in mind. Mechanisms of these wrenches are not dust-tight; consequently, their performance is not entirely satisfactory under the rugged conditions of coal mine use. The manufacturers of pneumatic impact wrenches generally have failed to provide mine repair-shop mechanics with instructions as to the procedure required to repair and adjust these devices.

Dust Hazard in Drilling for Roof Bolting

In the first experimental installations of roof bolts in coal mines, the possibility of failure of the method was of such concern to the mine officials that it was very difficult to encourage them to request additional appropriations for water pipe lines or tank cars from their respective companies. Frankly, we considered that it was more important to obtain experimental installations to prove the practicability of the method, leaving dust control a secondary consideration, than to insist upon adequate dust control and possibly impair the interest in making experimental installations. However, early in 1949, when roof bolting became popular and our field men gained enough experience so that they could forecast the approximate results after examining proposed places of installation, it was difficult to convince these new users that dust-control measures should be adopted at their particular mines, especially when some of those who had made the original experimental installations had not considered making provisions for dust control.

The standard effective method of dust control with pneumatic percussion drilling for many years has been to force water under pressure through hollow drill steel to the bit, and over the years the method has been enforced so rigidly, particularly in rock drilling in metal mines, that it has been taken as a matter of course, even though the drilling of vertical or near vertical holes is a sloppy, disagreeable task.

The coal miner, however, is an individualist, and regardless of any explanation that such wet-drilling is standard practice in metal mines, he is unimpressed and wants no part of such a disagreeable task. It is difficult for him to visualize the silicosis hazard to take it very seriously; therefore, he may be inclined to gamble with his future health for the sake of his immediate comfort. He does not offer serious objections to using a respirator when his boss is nearby but is inclined to discard it when not under direct supervision; however, if he wore a respirator continuously, others working "down-wind" from him might have no similar protection. Moreover, in many mines, especially those in which shuttle cars are operated on "fire-clay" floors, the large amount of water required to allay the dust from drilling effectively softens the fire clay, and the churning action of the rubber-tired shuttle-car wheels produces mud holes in the mine floor.

Experimental installations were made in a few bituminous-coal mines with pneumatic percussion drills operated wet; no labor trouble or operating difficulties arose. At one large mine, however, an experimental installation was started with dry drilling; later, after the method proved to be effective, both labor and operating difficulties occurred, and several months elapsed before the rate of drilling wet equaled that when drilling dry.

Attempts have been made to use high-speed, electric, rotary coal drills, designed for horizontal drilling, in vertical drilling for roof bolting, but water could not be applied at the bit to control the dust. The design of such a drill makes it virtually impossible to prevent the stream of water falling from the hole from entering the drill-motor casing. Two manufacturers are developing rotary drills in which power is transmitted hydraulically.

Some company representatives and others are studying the possibilities of developing a dust collector to collect dry dust, as it is produced at the collar of the drill hole, as effectively as dust can be controlled with wet-percussion drilling. At least one dust trap being developed is reported to be superior in eliminating fine dust from the mine atmosphere to conventional wet drilling.

RESEARCH

Although considerable theoretical information has been published on the subject of roof control, woefully little knowledge is available that can be applied practically by the mining engineer. The Bureau of Mines is equipping a roof-control laboratory at College Park, Md., and a crew is at work in the field with a newly developed "stratascope" to provide basic engineering data that we hope will supply this need. Preliminary experiments show considerable promise, but it will probably be some time before such information is available; therefore it is premature to discuss it now.